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FINAL REPORT

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VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

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- Performed research on signal detection by investigating techniques to reduce the false alarms of detectors at a constant signal detection threshold, by integrating and testing long-period signal extraction algorithms, by testing previously developed magnitude estimation models and their effect on determining $M_s - m_b$ at low thresholds of M_s .
- Defined an event identification package with a set of identification criteria applied to a network of station data, determined an optimum combination of the various criteria, tested the package on an area of interest data base provided by the government, and recommended further improvements based on operational difficulties and deficiencies discovered during the study.
- Performed a surface wave source mechanism study using SRO, ASRO, HGLP, and existing VELANET array data, compared eastern Kazakh explosions and Soviet PNE to selected NTS explosions, compared tectonic mechanisms of explosions to earthquakes selected to be as close as possible to known test sites, and evaluated the long-period surface wave moment- m_b relationship as a possible discriminant.
- Developed seismic data management software for retrieval of ILPA data from the Mass Store Data Retrieval System (MSDRS).

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ABSTRACT

↓ The second part of the work performed on Contract Number F08606-77-C-0004 has been reported in detail in a series of nine technical reports. This final report summarizes the material covered in each technical report prepared in FY78 and discusses conclusions obtained. Five major task areas were covered as follows:

- Evaluated SRO and ASRO stations by expanding the data base of operational stations to include at least one calendar year of data to determine the detection and discrimination capability of the stations, and to determine the performance characteristics of the detector used at the stations.
- Performed research on signal detection by investigating techniques to reduce the false alarms of detectors at a constant signal detection threshold, by integrating and testing long-period signal extraction algorithms, by testing previously developed magnitude estimation models and their effect on determining $M_s - m_b$ at low thresholds of M_s .
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SECTION I

INTRODUCTION

This final report summarizes the second part of the work performed under Contract Number F08606-77-C-0004, entitled VELA Network Evaluation and Automatic Processing Research, by Texas Instruments Incorporated at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The first part of this contract work covering the period 1 October 1976 to 30 November 1977, was summarized in Quarterly Report No. 5 (Texas Instruments Incorporated, 1978). The work on the second part, conducted during the period 1 December 1977 to 30 October 1978, consisted of the following five tasks:

- Evaluated SRO and ASRO stations by expanding the data base of operational stations to include at least one calendar year of data to determine the detection and discrimination capability of the stations, and to determine the performance characteristics of the detector used at the stations.
- Performed research on signal detection by investigating techniques to reduce the false alarms of detectors at a constant signal detection threshold, by integrating and testing long-period signal extraction algorithms, by testing previously developed magnitude estimation models and their effect on determining $M_s - m_b$ at low thresholds of M_s .
- Defined an event identification package with a set of identification criteria applied to a network of station data, determined an optimum combination of the various criteria, tested the

package on an area of interest data base provided by the government, and recommended further improvements based on operational difficulties and deficiencies discovered during the study.

- Performed a surface wave source mechanism study using SRO, ASRO, HGLP, and existing VELANET array data, compared eastern Kazakh explosions and Soviet PNE to selected NTS explosions, compared tectonic mechanisms of explosions to earthquakes selected to be as close as possible to known test sites, and evaluated the long-period surface wave moment- m_b relationship as a possible discriminant.
- Developed seismic data management software for retrieval of ILPA data from the Mass Store Data Retrieval System (MSDRS).

The detailed results obtained for these tasks have been presented in a series of nine technical reports and three software documents. This final report summarizes their results in Sections II through VI. References are given in Section VII, and a list of all reports issued under this contract is in the Appendix.

SECTION II

EVALUATION TASK

The results of this task are presented in Technical Report No. 13. The contents and conclusions are summarized below.

Technical Report No. 13: Continuation of the Seismic Research
Observatories Evaluation (ALEX(01)-TR-78-01)

A. THE EVALUATION TASK

This report presents the results of a continued evaluation of the Seismic Research Observatory (SRO) and the Abbreviated Seismic Research Observatories (ASRO). The specific goals of this evaluation were:

- To estimate the data quality and reliability of each station
- To investigate the short-period and long-period noise field characteristics of each station
- To evaluate the performance of the short-period automatic detector
- To estimate the detection capability of each station on events from Eurasia
- To estimate the discrimination capability of each station on a regionalized basis
- To investigate the performance of the stations as a network.

B. SUMMARY OF RESULTS

1. Data Quality

- In general, the data quality was good. At all stations except Zongo, Bolivia (ZOBO), data were degraded by malfunctions less than 4% of the time. Most ZOBO malfunctions were caused by a defective field tape. Other malfunctions were mostly glitches in the signal gate.
- Estimates of station reliability were based on the frequency of occurrence of malfunctions and on estimates of station down-time. ZOBO and Matsushiro, Japan (MAJO) both showed low reliabilities of approximately 0.7 due to relatively large amounts of station down-time. The other stations had reliability figures above 0.8.
- The frequency of mixed event occurrence for long-period waveforms ranged from a low of 0.19 for Chiang Mai, Thailand (CHTO) and MAJO to a high of 0.46 for station ZOBO. The frequency of mixed event occurrence is high for ZOBO Eurasian events because of the long distance between that station and Eurasia as compared to other stations.

2. Short-Period Automatic Detector

- During the time period that the detector was studied, detection probability, P_D , ranged from 50% to 80% while the false alarm rate (FAR) varied between 0.2 and 2.1 false alarms per hour. P_D seemed rather independent of FAR; this may reflect FAR instability inherent in straight STA/LTA-type detectors.

- Detector parameter setting and freezing practices have improved from 1976 to 1977 as evidenced by a more stable relationship between percent time recorded and number of detections.

3. Noise Analysis

- In order of increasing magnitude the mean short-period RMS noise values in the 0.5-4.0 Hz passband (uncorrected for instrument response) are: 1.02 m μ at ZOBO, 1.67 m μ at CHTO, 1.94 m μ at Kabul, Afghanistan (KAAO), 3.53 m μ at MAJO, and 5.55 m μ at Charters Towers, Australia (CTAO). These values show a strong correlation with station-coastline separation, indicating that a majority of short-period noise is derived from ocean wave energy injected at the coastline.
- Long-period RMS noise level and trends were investigated in the passbands: 10-25, 17-41, and 40-64 seconds. A year's worth of noise data were available for three stations, Albuquerque, New Mexico (ANMO), Mashhad, Iran (MAIO), and CTAO. Noise levels for these stations seemed to change seasonally in the 10-25 and 17-41 second passbands. However, trends in the 40-64 second passband noise levels are not easily explained.
- In general, no correlation was suggested by the data between long-period noise level or spectral content and station-coastline separation.
- A comparison between VLPE and SRO/ASRO instrument response corrected spectra for the same sites show significant improvements in noise levels after the installation of borehole seismometers. ASRO instruments showed strong correlation between noise amplitude and noise variance in contrast to their VLPE counterparts.

4. Detection Capability

- Actual 50% m_b short-period Eurasian detection capabilities are: 4.95 at CHTO, 5.43 at CTAO, 4.26 at KAAO, and 4.91 at MAJO.
- Only two short-period events were detected by ZOBO, proving this station a poor detector of Eurasian events.
- Actual 50% m_b long-period Eurasian detection capabilities are: 4.56 at CHTO, 5.05 at CTAO, 4.07 at KAAO, 4.36 at MAJO, and 5.26 at ZOBO.
- Mixed events had very little effect on short-period detection capabilities. Their effect is significant on long-period detection capability, especially at ZOBO.
- The automatic short-period detector as compared to analyst microfiche detection, showed an average loss of 0.12 m_b units in detection capability.
- Station down-time cost MAJO about 0.5 m_b units in detection capability. Down-time for ZOBO also significantly affected its detection capability. Actual detection capabilities for both stations should improve as all apparent hardware problems have been solved.

5. Discrimination

- Stations CHTO, CTAO, ZOBO, KAAO, and MAJO classified four out of fourteen presumed nuclear explosions with some confidence on the basis of an M_s - m_b criterion. Some indication of classification was noted for all but one of the events which were detected, suggesting that these stations would function best as part of a discrimination network.

- The following $M_s - m_b$ relationships were established.

CHTO: $M_s = 1.86 m_b - 4.92$

CTAO: $M_s = 1.73 m_b - 4.31$

ZOBO: $M_s = 1.52 m_b - 2.66$

KAAO: $M_s = 1.66 m_b - 3.71$, and

MAJO: $M_s = 5.33 m_b - 21.30$

The anomalous relationship for MAJO could not be explained.

Future work on the evaluation of the Seismic Research Observatory stations should be directed toward the following points:

- Evaluate all stations as they become operational.
- Expand the short-period and long-period noise data bases so that at least one year of data is available at each station for the study of noise level trends.
- Data bases should be individually tailored for at least those stations which are far from Eurasia. In this respect, ZOBO should be re-evaluated in such a way that its detection capability is measured more relevantly.

SECTION III

SIGNAL DETECTION TASKS

The results of these tasks are presented in Technical Reports No. 14 through No. 19, inclusive. The contents and conclusions are summarized below.

A. Technical Report No. 14: Extraction of Seismic Waveforms (ALEX(01)-TR-78-02)

By means of an expanded data base, it was intended in this report to better define the detection capability improvement due to application of cascaded signal extraction techniques. By applying Ringdal's method for magnitude bias correction (Ringdal, 1975; Strauss, 1978) it was possible to investigate the effects on the $M_s - m_b$ relationship of extending the detection capability of a station by the cascade method.

1. Goals

- To investigate the failure of the particle-motion polarization filter to improve the Guam SRO detection capability of Kurile Islands-Kamchatka events.
- To determine the value of particle-motion polarization filters when applied to teleseismic signals recorded at another station.
- To investigate the feasibility of applying particle-motion polarization filters to short-period near-field data.
- To obtain better estimates of the detection capability improvement due to the application of cascaded signal extraction techniques to long-period surface wave data.

- To determine the effects on the $M_s - m_b$ relationship of cascaded signal extraction techniques.
- To discuss the nature of the phase-difference polarization filter as applied to near-field and teleseismic data.

2. Conclusions

The following conclusions have been reached during the course of the work performed on signal extraction techniques:

- Both the bandpass filter-three-component surface wave adaptive processor and the Wiener filter-three-component surface wave adaptive processor cascaded combinations lower the 50 percent detection threshold by 0.5 m_b units.
- Surface wave magnitudes (M_s) measured on data processed by the bandpass filter-three-component surface wave adaptive processor are comparable to surface wave magnitudes measured on the corresponding bandpass filtered data, showing a gradually increasing separation from the surface wave magnitudes measured on bandpass filtered data as m_b decreases. For a given m_b , the variance of these M_s values is approximately the same as the variance of the M_s values measured on bandpass filtered data.
- Surface wave magnitudes (M_s) measured on data processed by the Wiener filter-three-component surface wave adaptive processor are not comparable to surface wave magnitudes measured on the corresponding bandpass filtered data. For a given m_b , the variance of these M_s values is much larger than the variance of the M_s values measured on bandpass filtered data.

- After correction for positive surface wave magnitude bias using Ringdal's technique, the M_s - m_b relationships derived from applying the bandpass filter and the bandpass filter-three-component surface wave adaptive processor have nearly parallel slopes throughout their range of definition from the 25 percent detection threshold to the largest m_b event of the data base.
- The poor performance of the particle-motion polarization filter when applied to Kurile Islands, Kamchatka events as recorded at Guam appears to be due to the station lying near a null in the bodywave radiation patterns and, in the case of shear waves, to distortion of the shear wave particle-motion by surface waves.
- When applied to Kurile Islands, Kamchatka events as recorded at Mashhad, Iran, the particle-motion polarization filter produces an improvement in the 50 percent detection threshold of 0.3 m_b units for P and 0.4 m_b units for S.
- Below the 50 percent detection threshold, the attenuation of P wave signals caused by the particle-motion polarization filter becomes significant, making difficult the measurement of long-period m_b for events detected only after being processed by this filter.
- Unless a detailed study of the apparent angles of incidence of P_n , P^* , P_g , S_n , S^* , and S_g is first carried out, it is not feasible to apply the particle-motion polarization filter to near-field short-period bodywaves.
- Preliminary testing indicates that the particle-motion polarization filter may be useful in the extraction of teleseismic short-period bodywaves.

- When applied to long-period bodywaves from Kurile Islands, Kamchatka to Mashhad ($\Delta \sim 66^\circ$), the phase-difference polarization filter improves the 50 percent detection threshold by approximately 0.5 m_b units.
- The attenuation of P waves due to application of the phase-difference polarization filter appears to be less than the attenuation due to the application of the particle-motion polarization filter.
- In addition to improving the detection thresholds of short-period and long-period bodywaves and surface waves, the phase-difference polarization filter offers the analyst a tool to separate the component phases of a seismogram, making possible more detailed studies of these phases than was previously possible.

3. Recommendations for Future Work

The following points should be considered for any future work using the signal extraction techniques discussed in this report:

- Since the presence in the signal gate of packets of 20-second energy proved to be a strong detection criterion for the cascaded processor surface wave extraction effort, it would be advisable to try narrowband filtering the data before applying the three-component surface wave adaptive processor.
- A large data base of short-period events should be processed by the phase-difference polarization filter to determine its effect on short-period detection and discrimination.
- It might be fruitful to attempt cascading of the particle-motion and phase-difference polarization filters, since together the models used in these filters completely describe the polarization

of the seismic waveforms. This should have the effect of improving the detection thresholds while decreasing the probability of false alarms.

B. Technical Report No. 15: Application of Ringdal's Method to Unbiased Measurement of the $M_s - m_b$ Relationship (ALEX(01)-TR-78-03)

1. The Magnitude Bias Problem

Magnitude bias considered here is grounded in two different physical phenomena - the effect on signal detection of source-to-station statistical variation in signal amplitude for seismic events due to source, path, and local receiver effects, and each stations' temporal statistical variation of the seismic noise levels. These factors influence the signal-to-noise ratio variation between observations which in turn determines that only the larger signals from an event are used to estimate the event magnitude. The net result is a positive bias in the event magnitude, which increases as the true event magnitude decreases.

A method for removing this positive magnitude bias was developed by Ringdal (1975). In brief, his method is to measure signal magnitudes at the detecting stations and to determine upper bounds on the signal magnitude at the non-detecting stations by measuring the magnitude of noise at the station as though it were a signal. A maximum likelihood estimate of the true network magnitude and standard deviation is then computed from those measurements.

2. The Task

The primary goal of this report was to test Ringdal's method of correcting magnitude bias. In the course of carrying out this test, the following points were covered:

- Design an experiment to carry out this test.
- Determine the differences between conventional network magnitude estimates and the estimates derived from Ringdal's method.
- Describe qualitatively the conditions under which Ringdal's method can be expected to function properly.
- Determine the effect of Ringdal's method on the $M_s - m_b$ discriminant.

3. Conclusions

The following conclusions have been reached in the course of this test of Ringdal's method of removing positive magnitude bias:

- Surface wave magnitudes are strongly affected by positive magnitude bias for events with bodywave magnitudes below the 90 percent detection threshold.
- Below this detection threshold, this bias is the controlling factor in the trend of the $M_s - m_b$ relationship.
- Ringdal's method successfully removed the bias from the surface wave magnitudes for events with bodywave magnitudes down to approximately the 25 percent detection threshold.
- For good results, the method requires at least three detections with corresponding signal magnitudes.
- The earthquake $M_s - m_b$ relationships derived from unbiased ALPA-recorded surface wave magnitude data are:

Single Site	$M_s = 1.09 m_b - 1.47$	$4.0 \leq m_b \leq 4.9$
	$M_s = 1.53 m_b - 3.61$	$4.9 \leq m_b \leq 6.2$
Array	$M_s = 1.14 m_b - 1.79$	$4.0 \leq m_b \leq 4.9$
	$M_s = 1.55 m_b - 3.79$	$4.9 \leq m_b \leq 6.2$

- For presumed explosions with m_b at or above the array 100 percent detection threshold of surface waves, removal of magnitude bias brought the M_s of single site observations into line with the trend of array data.

4. Recommendations

The results of this study also indicate that an in-depth investigation of M_s - m_b relationships using unbiased mean M_s data would be fruitful. In particular, more earthquakes are needed to better establish the M_s - m_b least-squares trends for various ranges of m_b .

The difficulty of assembling a sufficient large explosion data base at any one station could be circumvented by removing the station instrument response and by comparing similar measurements of M_s at all stations at all times. A study of this nature can be used to test the hypothesis that the earthquake and explosion M_s - m_b relationships are parallel.

C. Technical Report No. 16: Narrow and Broad Region Dispersion of Long-Period Surface Waves (ALEX(01)-TR-78-04)

In this report, we discuss the Kuriles-Kamchatka-to-Guam dispersion data, and their effect on long-period surface wave polarization filtering. Also described are compositions of broad region dispersion models, and an ensuing special purpose dispersion related filtering algorithm.

Narrow region dispersion analysis of Kuriles/Kamchatka earthquake signals recorded at Guam, by means of moving-window maximum entropy spectral analysis, indicates strong multipathing in the 3.0 to 4.5 km/sec group velocity range, causing poor polarization filter performance. In contrast, between 2.0 and 3.0 km/sec the signals are well defined, resulting in a good polarization filter response. The dispersion for this region seems quite diverse.

Broad region dispersion models for the North American and Asian continents were generated using previously reported group velocity data for Nevada Test Site and Eastern Kazakh presumed nuclear explosion signals recorded at world-wide stations. These models facilitate frequency-dependent surface wave magnitude measurement.

D. Technical Report No. 17: Short-Period Noise Envelope Statistics:
A Basis for Envelope Detection Design (ALEX(01)-TR-78-05)

1. The Detection Statistics Problem

This report focuses on the use of certain detection statistics, in particular the instantaneous amplitude or envelope, and the instantaneous power, in the design of a controlled false alarm rate detector. To achieve false alarm rate control, the detection statistic must be stationary, but need not be Gaussian. Parameters of a Gaussian process can be conveniently transformed into a stationary, normalized detection statistic. For an envelope detector the normalization consists of dividing the envelope by a long-term (1 to 2 minutes) estimate of the RMS noise level; the instantaneous power is normalized by dividing it by the long-term average power.

The stationarity of the normalized envelope is demonstrated with one hour of uninterrupted, Korean Seismic Research Station single-site, short-period noise, by compiling distributions of the base-ten logarithm of the normalized envelope. The envelopes closely follow the Rayleigh distribution which is the theoretical distribution for envelopes of a Gaussian process.

2. Conclusions

Distributions of the base-ten logarithm of instantaneous amplitude (envelope) values from one hour of uninterrupted, unfiltered KSRS single-site, SP noise were analyzed. The one-hour noise sample was divided into 102.4-sec data segments. Taking 0.4-sec envelope samples, the long-envelope

distribution was compiled for each data segment, in 2 dB bins. The evaluation led to the following conclusions:

- For envelopes of this one-hour seismic noise sample, the Rayleigh distribution can be retained at the 5% significance level based on a Kolmogorov-Smirnov test.
- A stationary normalized Rayleigh detection statistic is obtained by dividing the seismic noise envelope values by a long-term (1 to 2 minutes) running estimate of the RMS noise.
- For a single detection trial, a tolerable false alarm rate can be maintained merely by setting the envelope signal detection threshold at a fixed level above the RMS noise level.
- Employing multiple detection criteria can further reduce the false alarm rate.
- For Rayleigh-distributed envelopes, the theoretically most likely value of the ratio between the maximum noise envelope and the RMS noise level is 10 to 12 dB as is routinely observed by seismogram analysts. Employing a threshold of 3 dB above this maximum may result in a near-constant false alarm rate. This detector may exhibit a relatively stable performance also under non-Gaussian noise conditions.
- A recently developed envelope detector (Unger, 1978) reported one false alarm over the one-hour noise sample. Determination of reliable operating characteristics for this detector model requires further empirical evaluation.
- A detection statistic need not be Gaussian for false alarm rate control; it merely has to be stationary. Detection statistics derived from a time-varying Gaussian process can often be

transformed into stationary detection statistics, e. g., normalization of envelope statistics.

- Fluctuations of the noise spectrum cause the short-term average (STA) of a detection statistic to be non-stationary (Lacoss, 1972; Steinert et al., 1975); this explains the reported false alarm rate instability in straight STA/LTA detectors. The STA/LTA false alarm rate can be stabilized by proper normalization of the STA statistic (Lacoss, 1972; Swindell and Snell, 1977).
- Short-term averaging, followed by STA normalization, may enhance the detector operating characteristics in the sense of performing a likelihood ratio test for multiple trials or observations in the detection of signals of constant amplitude. It also may provide a means of controlling the false alarm rate for non-Gaussian noise.
- For signals of non-constant amplitude, such as most seismic signals, it is difficult to analytically optimize the detector design. A combination of analytical and empirical evaluation seems necessary. In particular, the strategy of normalized STA/LTA detection (e. g., Swindell and Snell, 1977) should be compared to that of employing multiple, independent detection trials and multiple detection criteria based on instantaneous detection statistics (Unger, 1978).
- In designing a detection sampling strategy, it is extremely important to adapt to fluctuations in the average time interval between independent noise samples.
- Any model adopted should be tested on noise data recorded at different times of day and year, and at a variety of stations.

Sufficiently long detector runs should be carried out to establish the validity of the noise model in predicting the occurrences of noise alarms in the tail of the distribution, i. e., at false alarm rates sufficiently low for optimum network operation.

E. Technical Report No. 18: Detection Performance of Time-Varying Adaption Rate Adaptive Beamformers (ALEX(01, -TR-78-06)

1. Detection Performance

This report presents an evaluation of the detection performance for the time-varying adaptation minimum power adaptive beamformer (ABF). The ABF is essentially based on the L_1 Norm Least-Square Formulation. The ABF algorithm described by Shen (1977) was modified in this report to adapt to various levels of noise in the operating environment. The detection performance study is based on the modified algorithm in which the design parameters are kept constant to demonstrate the algorithm's ability to be implemented for operational purposes.

Another element discussed in this report is the problem of coda rejection. The ABF capabilities for coda rejection can be automatically applied in a front-end detection system (Shen, 1978a, b). The coda of seismic signals from strong earthquakes consists of substantial high amplitude and long duration wavetrains. These could be due to the complex nature of source functions and/or the scatterings of waves caused by the complex structure in the media along the propagation paths. Under these circumstances, an automatic signal detector is jammed, or continuously yields false alarms and loses its functions for a certain period of time before returning to normal operation.

2. Conclusion

The ABF was developed as an array processor for signal detection and extraction. There is no need to inject a pilot signal for noise statistics to train the system. The ABF can be implemented as a front-end detector.

Using the KSRS short-period array data, evaluation for its detection performance has been accomplished in terms of its capability to suppress coda wavetrains or the scattered energy following the initial arrival, to enhance the secondary P wave phases, accuracy of its m_b measurement, and estimate of its detection probability as compared with the conventional beamsteer. A total of 129 events were used. On the average, the ABF yielded the same magnitude difference of 0.1 m_b units as the beamsteer when compared with the bulletin m_b . However, the ABF improved the KSRS detection capability by 0.5 m_b units for the conventional beamsteer as suggested from the statistical estimate of the processed results. This result is based on an analyst interpretation of the detection status of the beamformed data. For a more precise evaluation these results must be further verified with an extended data base, and in an objective manner by subjecting the beamformed outputs to an automatic detector.

F. Technical Report No. 19: Feasibility Study of Mixed-Signal Separation Techniques (ALEX(01)-TR-78-07)

1. Separation of Mixed Signals

By employing array beamforming techniques which we developed, we evaluated the feasibility of using arrays to separate mixed signals which are weak signals occurring after strong signals. They are difficult to detect due to the coda or scattered energy of the preceding stronger signal interfering or overshadowing the later arriving weak signal. The problem

here is how to reject the high-amplitude interfering wavetrains of the stronger earthquake and how to extract the weaker hidden signal from the interfering environment.

Two array beamforming techniques were studied for this purpose: one in the time domain can be used as a front-end detector and the other in the frequency domain is intended as a post-detection processor.

In the first technique, the ABF algorithm described by Shen (1977) was modified; in the second, a mathematical algorithm for an array-shading technique was formulated. Computer programs were developed for computations on Korean Seismic Research Station (KSRS) short-period array data. A description is given of the adaptive beamforming algorithm. Also described is the physical formulation of array weighting algorithms and their computational results. Experimental procedures and results from the recorded-data tests are presented followed by conclusions and suggestions for further study.

2. Conclusions

Using the recorded data from the KSRS short-period array, a composite data tape was formed to simulate the recorded mixed signal data by adding the data of high amplitude signal wavetrains from a seismic event in the Ceram Sea to those of a low amplitude signal (noise level) from a seismic event in Tadzhik. The ABF processor outputs in wide band (0.5-3.5 Hz) and in narrow bands (0.5-1.5 Hz, and 1.5-2.5 Hz) showed that the interfering wavetrains were successfully eliminated and the desired weak signal was clearly enhanced to a detectable level, while the desired signal in beam-steer outputs was at the level of interfering wavetrains and was non-detectable. The experimental test of the real-amplitude shading algorithm indicated that the results were promising and deserve further study. However, the complex-shading algorithm did not yield the satisfactory results predicted from beam

pattern computation. Real amplitude weighting appears to be a sufficient tool for studying mixed-signal problems.

In conclusion, we felt that the present ABF is a powerful real-time array processor and the real-amplitude shading technique could be useful for post-processing the coda of large signals.

3. Suggestion for Further Study

The preliminary experimental results suggest that real-amplitude shading techniques are potentially useful for removing the coherent interfering energy and for extracting a hidden signal in a coherent interfering environment. A useful approach would be to bury a signal from an underground nuclear explosion in various types of interfering environments. A systematic study could be made and a set of filter weights could be designed from the study so that they could be used for post-detection searches for hidden explosions or other research purposes.

The real-amplitude shading algorithm was formulated for a single-frequency signal that was applied to a relatively narrowband signal. A wide band signal can be synthesized by summing the data of various frequencies.

SECTION IV

EVENT IDENTIFICATION

A. Technical Report No. 20: Event Identification - Application to Area of Interest Events (ALEX(01)-TR-78-08)

1. Systematic Approach to Event Identification

An integrated event identification system has been developed to operate on an 'Area of Interest' data base. This system includes an automated measurement and analysis section using the IBM 360/44 computer and an interactive editing and identification section using the PDP-15/50 computer. Amplitude measurements are made on both short-period and long-period data and serve as the basis for computing most of the discriminants. Other discriminants include mean instantaneous frequency and mean instantaneous phase standard deviation, and complexities. Ringdal's maximum likelihood technique is used to generate 'unbiased' event measurements from the individual station measurements obtained for each event. At present, a set of 35 events has been processed with this system. A multivariate analysis technique was used to classify the events either as earthquakes or as particular types of anomalous events. The results indicate that such a system makes it possible to achieve good separation between anomalous events and a selected set of normal shallow-depth earthquakes.

2. The Task

Since no one discrimination technique can be expected to correctly identify all events from all regions as recorded at all stations, it is necessary at this time to attempt to identify events using all available discrimination information in a multivariate mode of operation.

The specific goals were:

- To define a set of identification criteria which can be applied to network data to optimally use the features of each discrimination method.
- To determine the physical source of each discrimination method in order to allow the application of the method to events of similar physical characteristics.
- To assemble a package of discrimination techniques and test this package in order to define how the techniques perform, both individually and in a multivariate mode.
- To recommend further package refinements based on any deficiencies or operational difficulties discovered during the course of this study.

3. The Area of Interest Data Base

The data base to be used in this event identification study is the suite of 'Area of Interest' (AI) events supplied to all researchers by Tele-dyne Geotech Incorporated of Alexandria, Virginia. These edits nominally consist of 180 seconds of short-period P, 600 seconds of short-period Lg, 240 seconds of each of long-period P and S, and 1200 seconds of long-period Rayleigh, where the edit windows are roughly centered about the expected arrival time of the appropriate waveform. The only change made in the data when preparing the AI tapes was to convert the data from digital counts to millimicrons. The data from all stations except Red Knife, Ontario (RKON) and Holton, Maine (HNME) are in the vertical, north, east configuration. The data from RKON and HNME were recorded in a vertical, transverse, radial configuration with respect to the Nevada Test Site.

Several problems were encountered with the AI data when processing was initiated. First, it was found that the waveform identification scheme was not always followed when the AI data tapes were created. According to a memorandum issued by Teledyne Geotech Incorporated, each waveform was to have a unique seismogram number identifying the event, recording station, type of data (short-period or long-period), and propagation mode (P, S, Lg, or Rayleigh). However, it was found that, for more recently created AI tapes, it was not uncommon for only one seismogram (identified as long-period P) containing long-period P, S, and Rayleigh to be on the tape. Thus, one cannot with confidence create a program to search on the basis of seismogram number for one propagation mode but must either check header dumps of the tapes or have the program check each waveform for the desired time window based on start time and length of the edit and expected arrival time of the desired propagation mode.

A second problem was that in no case was there a specific short-period Lg edit available from any of the SRO or ASRO stations. Although the short-period automatic detector installed at these stations must be held responsible in most cases for this lack of Lg data, one would expect Lg edits for some of the SRO/ASRO recorded events, since, as shown by Strauss and Weltman (1977), at some stations the automatic detector after being triggered will often stay on for long periods of time. Thus, one would expect there to be at least an occasional Lg edit for these stations on the AI tapes. This unfortunate lack of Lg edits also occurred for data recorded at the stations which continuously record short-period data. It was not uncommon to have a short-period P wave edit but no Lg edit where one would expect the data to have been available.

A surprising shortcoming of the AI data base is the absence of short-period S wave edits. Occasionally, an S wave can be found in the P wave edit when the station is near the event epicenter. However, no specific

S wave edits were made during the completion of this data base. This lack of short-period S wave data, coupled with the scarcity of Lg data, seriously affects the quality of the event identification effort, since it minimizes the utility of the compressional-to-shear ratio type of discriminants which have been proven quite useful in the past (Booker and Mitronovas, 1964).

B. Conclusions

Our goal was to develop a package to objectively evaluate the performance of a set of selected discriminants as potential components of a seismic event identification system. As a ground rule, the following operations were performed automatically to achieve an objective evaluation of performance.

- Determine ground motion by correcting for system response.
- Edit phases.
- Extract waveforms and determine detection status.
- Filter waveforms.
- Generate a signal measurement file.
- Generate an event source measurement file by operating on the signal measurement file.
- Generate an event discriminant file by operating on the source measurement file.
- Generate inductive grouping of event types by operating on the discriminant file.

The final results of this mode of discriminant processing are reproducibly determined subject to specification of a set of algorithms for determining the detection status of edits, algorithms for measuring signals or noise in edit

windows, algorithms for converting signal measurements to unbiased estimates of source parameters, algorithms for converting derived discriminants from source parameter measurements, and decision functions for grouping events of similar discriminant characteristics. In addition, to start the process it was necessary to introduce a training set of normal shallow earthquakes, determine the statistical characteristics of their discriminants and use those characteristics to normalize the observed discriminants of subsequent unknown events.

Our initial test run was performed on thirty five events, twelve of which were selected as the initial normal shallow earthquake training set. Of the unknown set, six were correlated with normal shallow earthquakes and fourteen were correlated with a similar group of events which are not normal shallow earthquakes, and three remained as unknown unusual events which were neither classified as normal shallow earthquakes nor as the correlated group of unusual events. This test was performed with arbitrarily selected decision thresholds for grouping events. Based on statistics determined from the test and the observed grouping of events a threshold can be set to operate with any desired operating characteristics. For example, two normal earthquakes appeared to be included in the correlated group. By raising the threshold, the two apparent normal earthquakes could have been classified correctly without removing any other events from the correlated group. Two of the unknown unusual events were deep events from the Afghan-USSR border which appear to be similar to each other. The third unusual event was an intermediate depth event from the Kurile Islands.

Relative ranking performance of particular discriminants are apparent by examination of tables of likelihood tests and detectabilities given in the report. It should be kept in mind, however, that such rankings of discriminant effectiveness are only relevant to the single correlated group thus far obtained. Other apparently less effective discriminants may be important

in detecting members of other unusual event groupings not yet observed. Once the decision rules are set, the package provides a multi-user environment. The classification files can be used as permanent, maintainable and transportable files. As more events are added into such a system, the performance will improve as a result of building up the grouped populations of abnormal events and normal earthquake populations. This will result in better statistical estimates of population characteristics. In another sense, better performance can be anticipated by expanding the list of discriminants and the number of stations in the network.

SECTION V

SURFACE WAVE STUDY

A. Technical Report No. 21: Application of a Combined Source Model for Seismic Discrimination (ALEX(01)-TR-78-09)

The purpose of this study has been to use the observed long-period teleseismic surface wave data of earthquakes and presumed underground explosions to determine the source mechanisms and to use these source mechanism estimates to discriminate between the two classes of events. In order to demonstrate this purpose, fifteen events have been selected and analyzed for the Russian Eastern Kazakh (EKZ) region, central and northern Eurasia, and the United States Nevada Test Site (NTS).

The observation stations available for this study included the Seismic Research Observatory (SRO), Abbreviated Seismic Research Observatories (ASRO), the High Gain Long-Period (HGLP) stations (the same as the previous VLPE), and existing VELANET array data.

For a fair comparison of explosion and earthquake events, both have been treated in the same way by using the combined source model which combines a point explosive source and a point double-couple source.

In order to cut down computer expenses and widen the searching range of some parameters, a binary exhaustive search method was applied to modify the amplitude spectral fitting process without any constraint. The results obtained from this modified process gave very good spectral fits for most events and lowered the minimum residual fitting error of each event.

The estimated seismic moment was tested for its feasibility to discriminate between earthquakes and explosions. Taking the surface wave

seismic moment to be a universal scaling parameter for sizing events, the average m_b of explosions is expected to be approximately an order of magnitude greater than the average m_b of earthquakes. This would indicate more efficient radiation of high frequency P waves for explosions of equal moment. Since this criterion should apply equally to both Nevada Test Site and eastern Kazakh presumed explosions, it suggests that surface wave moment estimates may be a more universal parameter than M_s for scaling the size of earthquakes and explosions.

B. Conclusions

The following remarks summarize results concerning source parameter estimates obtained from surface wave data using spectral fitting procedures:

- For most events, the average spectral amplitude indicated the same aspect, namely, higher at shorter periods and decreasing toward longer periods, suggesting a very shallow focal depth.
- In general, the estimates of focal depth of the selected earthquakes closely agree with those determined from bodywave depth phases, but their distribution indicates a noticeable skew toward deeper depth estimates. The mean value of this distribution is located at a 3.5 km depth. Most events occur in the confidence area of this distribution; that is an area of depth occurring at 1.5 km to 4.0 km. For events NTS/212/76 and EKZ/1214/3, the estimated depths are 6.0 km and 8.0 km, respectively. The reason for this might be a close association with irregularities in crustal structure and, hence, the anomalous crustal rigidity or strength right beneath the shot point.

- No altogether consistent difference was observed between the F-value (ratio of dilatation to shear) of the explosion and earthquake population, but in most cases the estimates of F-value of explosions are smaller than those of earthquakes. This result is quite different from what we expected. The large F-value of earthquakes, especially for the two deeper events ECU/02/03/72 and TZK/03/17/72, might be caused by the volume change during the rupture at deep focal depth. The small F-value of explosions means that the double-couple source is dominant for surface waves at the periods considered. The association of higher F-values with deeper earthquakes suggests that a higher dilatational component is required to overcome the overburden pressure. The lack of dilatation of explosions, random strike and deeper focus suggests that the double-couple source of explosions may be associated with large displacements on a fracture zone surrounding the source. Radiation from the deeper part of the fracture zone is more visible due to the effect of the free surface.

C. Recommendations

It is recommended that future studies be directed toward the following points:

- Confirm the apparently universal surface wave moment versus m_b relationship with a much larger data base of earthquakes and explosions.
- Evaluate surface wave moment as a scaling parameter for estimating yields of explosions.

- Evaluate the sensitivity of source mechanism solutions to the distribution of stations and path corrections.
- Check the consistency of combined source mechanisms on a large earthquake and aftershock sequence.
- Develop feasible procedures for applying the combined source mechanism as an extended event identification technique.

SECTION VI

DATA MANAGEMENT

A. Software Documentation ALEX(01)-SD-78-01: Korean Seismic Research Station (KSRS) Data Transfer Documentation

This describes an edit and file transfer program for Korean Seismic Research Station (KSRS) data. The general task is to read the Korean data from a raw data tape; write the data on tape in a permuted form with status information obtained from an event summary file (ESF) furnished by Tele-dyne Geotech, Incorporated; and operate the file transfer program (FTP) to transfer the permuted and embellished data through a data language port into a data language file for later scientific analysis. The program was written to execute on a IBM 360/44 computer.

The method of attack is to write all long-period (LP) data for a given raw tape first on a 'reformat' tape, then 80-second segments of short-period (SP) data in another file, and coarse status (CS) information in the last data file.

The LP reformatted data consist of the three-component instrument array data, but no beam or multichannel data. They are written on the reformat tape as they are read from the raw tape.

The SP reformatted data consist ordinarily of the high gain integer data for a single three-component instrument and one beam, all reported for 80 seconds for each event furnished by an ESF tape.

The CS data on the 3rd data file of the reformat tape gives the time and data of the associated LP data and whether that LP data was available on the raw input tape.

As the raw tape is read, the LP data are written out on tape and all SP data of interest from 20 seconds prior to a computed arrival time to 60 seconds following the computed arrival time are written on disk. LP CS data are likewise stored in memory. When the raw tape has been completely read, the SP and CS files are transferred to the output tape from disk.

B. Software Documentation ALEX(01)-SD-78-02: ILPA Mass Store Data Retrieval Software Documentation

This documentation describes an interactive software package developed by Texas Instruments Incorporated (TI) for the purpose of retrieving Iranian Long Period Array (ILPA) seismic data and coarse status information stored at the Datacomputer in Cambridge, Massachusetts. Absent data, calibration times, and operator flagged and communication errors are marked in the coarse status information. This software package utilizes the interactive graphics facilities of the PDP-11/70 computer located at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The program is implemented under the UNIX operating system.

The documentation presents a functional description of the software package, which has been named the TI Datacomputer interface (TIDCI). The objective of the package, the operating system environment, and the hardware configuration are defined and the overall data flow is presented.

The documentation describes in detail the individual components of TIDCI. For each subroutine, the purpose is stated and a flow chart is given. Finally program execution examples of ILPA data and coarse status retrieval are presented.

The manual provides documentation and figures that describe the file and port formats and the node structure of the ILPA seismic data as it is stored at the Datacomputer.

C. **Software Documentation ALEX(01)-SD-78-03: Seismic Data Preparation Procedures**

A data preparation process was developed to prepare seismic data for analysis on the PDP-15 computer; the data flow is described briefly. The programs are being run by Texas Instruments Incorporated on the IBM 360/44 at the Seismic Data Analysis Center (SDAC). New programs developed during the contract period are described in some detail. Some suggestions for future work are provided.

SECTION VII

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Unger, R., 1978; Automatic Detection, Timing and Preliminary Discrimination of Seismic Signals with the Instantaneous Amplitude, Phase and Frequency, Technical Report No. 4, Texas Instruments Report No. ALEX(01)-TR-77-04, AFTAC Contract Number F08606-77-C-0004, Texas Instruments Incorporated, Dallas, TX.

APPENDIX A

LIST OF REPORTS FROM CONTRACT F08606-77-C-0004

A. QUARTERLY REPORTS

1. Quarterly Report No. 1; covering the period 1 October 1976 to 31 December 1976, Texas Instruments Report No. ALEX(01)-QR-77-01, 6 January 1977.
2. Quarterly Report No. 2; covering the period 1 January 1977 to 31 March 1977, Texas Instruments Report No. ALEX(01)-QR-77-02, 4 April 1977.
3. Quarterly Report No. 3; covering the period 1 April 1977 to 30 June 1977, Texas Instruments Report No. ALEX(01)-QR-77-03, 1 July 1977.
4. Quarterly Report No. 4; covering the period 1 July 1977 to 30 September 1977, Texas Instruments Report No. ALEX(01)-QR-77-04, 3 October 1977.
5. Quarterly Report No. 5; covering the period 1 October 1977 to 31 December 1977, Texas Instruments Report No. ALEX(01)-QR-77-05, 3 January 1978.

B. TECHNICAL REPORTS

1. Continuation of Iranian Long Period Array Evaluation, by Lynn A. Shaner and Alan C. Strauss, Texas Instruments Report No. ALEX(01)-TR-77-01, 30 December 1977.

2. Continuation of the Seismic Research Observatories Evaluation, by Alan C. Strauss and Leonard C. Weltman, Texas Instruments Report No. ALEX(01)-TR-77-02, 16 November 1977.
3. The Deflection Detector - Its Theory and Evaluation on Short-Period Data, by Mark J. Shensa, Texas Instruments Report No. ALEX(01)-TR-77-03, 2 November 1977.
4. Automatic Detection, Timing and Preliminary Discrimination of Seismic Signals with the Instantaneous Amplitude, Phase and Frequency, by Rudolf Unger, Texas Instruments Report No. ALEX(01)-TR-77-04, 27 March 1978.
5. Study of Adaptive Beamforming Algorithms for Low Magnitude Seismic P Wave Detection, by Wen-Wu Shen, Texas Instruments Report No. ALEX(01)-TR-77-05, 1 November 1977.
6. The Detection Association Processor, by Nolan S. Snell, Texas Instruments Report No. ALEX(01)-TR-77-06, 31 March 1978.
7. Extraction of Long-Period Bodywaves, by Stephen S. Lane, Texas Instruments Report No. ALEX(01)-TR-77-07, 14 November 1977.
8. Extraction of Long-Period Surface Waves, by Stephen S. Lane, Texas Instruments Report No. ALEX(01)-TR-77-08, 8 December 1977.
9. The Extended Interactive Seismic Processing System (ISPSE), by Jeffrey S. Shaub and David G. Black, Texas Instruments Report No. ALEX(01)-TR-77-09, 5 December 1977.
10. Seismic Data Preparation Procedures, by A. William Schmidt and Kimberly S. Wilson, Texas Instruments Report No. ALEX(01)-TR-77-10, 20 October 1977.

11. Determination of Seismic Source Parameters from Long-Period Surface Wave Data, by David Sun, Texas Instruments Report No. ALEX(01)-TR-77-11, 31 August 1977.
12. Relationships Between Noise and m_b Bias Applied to Seismic Station Site Selection and Performance Evaluation, by Donald L. Dietz and Robert L. Sax, Texas Instruments Report No. ALEX(01)-TR-77-12, 23 March 1978.
13. Continuation of the Seismic Research Observatories Evaluation, by Leonard C. Weltman and Robert R. Oliver, Texas Instruments Report No. ALEX(01)-TR-78-01, 20 November 1978.
14. Extraction of Seismic Waveforms, by Alan C. Strauss, Texas Instruments Report No. ALEX(01)-TR-78-02, 29 September 1978.
15. Application of Ringdal's Method to Unbiased Measurement of the M_s - m_b Relationship, by Alan C. Strauss, Texas Instruments Report No. ALEX(01)-TR-78-03, 31 August 1978.
16. Narrow and Broad Region Dispersion of Long-Period Surface Waves, by Rudolf Unger, Texas Instruments Report No. ALEX(01)-TR-78-04, 11 October 1978.
17. Short-Period Noise Envelope Statistics: A Basis for Envelope Detector Design, by Rudolf Unger, Texas Instruments Report No. ALEX(01)-TR-78-05, 26 September 1978.
18. Detection Performance of Time-Varying Adaption Rate Adaptive Beamformer, by Wen-Wu Shen, Texas Instruments Report No. ALEX(01)-TR-78-06, 15 September 1978.

19. Feasibility Study of Mixed-Signal Separation Techniques, by Wen-Wu Shen, Texas Instruments Report No. ALEX(01)-TR-78-07, 12 July 1978.
20. Event Identification - Applications to Area of Interest Events, by Robert L. Sax and Technical Staff, Texas Instruments Report No. ALEX(01)-TR-78-08, 13 November 1978.
21. Application of a Combined Source Model for Seismic Discrimination, by Helmut Y. A. Hsiao, Texas Instruments Report No. ALEX(01)-TR-78-09, 25 October 1978.

C. SOFTWARE DOCUMENTATION

1. Korean Seismic Research Station (KSRS) Data Transfer Documentation, by G. A. Hotelling, Texas Instruments Report No. ALEX(01)-SD-78-01, 31 August 1978.
2. ILPA Mass Store Data Retrieval Software Documentation, by David G. Black, Texas Instruments Report No. ALEX(01)-SD-78-02, 31 August 1978.
3. Seismic Data Preparation Procedures, by A. William Schmidt and Kimberly S. Wilson, Texas Instruments Report No. ALEX(01)-SD-78-03, 29 September 1978.

D. FINAL REPORT

1. Final Report, VELA Network Evaluation and Automatic Processing Research, by Robert L. Sax and Technical Staff, Texas Instruments Report No. ALEX(01)-FR-78-01, 22 November 1978.